Effect of Addition of Calcium Nitrate on Selected Properties of Concrete Containing Volcanic Ash

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Abstract

In this work, the effect of addition of Calcium Nitrate on selected properties of concrete containing Volcanic ash as partial replacement for ordinary Portland cement by weight was investigated .The study carried out used 10% volcanic ash as partial replacement and an admixture, $Ca(NO_3)_2$ Was added to improve the strength of the resulting concrete at 2%, 4%, 6% 8% and 10% respectively. The result of setting time showed a decrease in both initial and final setting time of the mixture as the $Ca(NO_3)_2$ Content was increased. The result of chemical analysis of volcanic ash showed an increase in calcium oxide (CaO) content when calcium Nitrate $Ca(NO_3)_2$ was added from 11.67% to 33.68%. Cubes were cast and cured in water for 7, 14, 21, and 28 days .The resulting Strength at 28 days hydration period shows a strength increase as the percentage of $Ca(NO_3)_2$ was increased to 10% .

Keywords

Admixture; Calcium Nitrate; Concrete; Volcanic Ash; Strength.

Introduction

Concrete is still the most extensively used construction material, since it has the lowest ratio between cost and strength as weigh against other available materials, its seen as been very versatile in nature and application. This concrete is made of some basic component such as aggregates (fine and coarse), cement (binder) and water. Cement (commonly ordinary Portland) which is unarguable an important material in the production of concrete is expensive compared to the other materials. This out of many other reasons as lead to the exploration for unconventional matrix or cement surrogate stuffs which had been an unrelenting effort for the most recent decades [1-8]. Wide-ranging research had been conducted over the last few years on the use of VA in cement and concrete production [1, 2, 9-11]. Research suggested the manufacture of blended OPC/VA (Portland volcanic ash cement) with maximum replacement of up to 20% [12]. Volcanic ash as described by Hossain [13] are pozzolanic stuffs, because of their reaction with lime (calcium hydroxide- $Ca(OH)_2$) liberated during the hydration of cement. Amorphous silica present in the pozzolanic materials (VA) combines with lime and forms cementitious materials. These materials can also improve the durability of concrete and the rate of gain in strength and can also reduce the rate of liberation of heat, which is beneficial for mass concrete.

Volcanic materials such as Volcanic ash are upshot of volcanic eruption (volcanoes) which are found abundantly in volcanic areas around the world e.g. Kerang in Mangu Local Government Area of plateau state, Nigeria and finding new and improved ways to build with such materials is becoming widespread. New sources of volcanic materials being produced steadily. The eruption of Mount Pinatubo in Philippines in the early 1990s devastated a fertile beautiful valley into a source of volcanic materials which was used as useful building materials for constructing affordable housing. The volcanic eruption that occurred at the mountainous Mkomon district of Kwande Local government of Benue State, Nigeria in 2010 left one person feared dead while properties worth millions of Naira were also destroyed. Residents of the affected community had deserted their homes in search of safer place. Sources of portable water have been polluted by the heavy magma emitted from the eruption.

There were heavy vibrations around the mountains at the border with Cameroun Republic, followed by eruptions at six points on the mountainous terrain. The vibrations spewed magma which covered streams and hand dug wells and the entire community leaving the people without portable water. There was panic amongst the people who are said to be cut off completely from the rest of the world as a result of the occurrence and damages to roads and bridges which was occasioned by the heavy vibration. The 1994 volcanic eruption that occurred in the East New Britain province of Papua New Guinea (PNG) completely devastated the province and created an environmental disaster [13]. Significant use of volcanic materials can, not only transform them into natural resources to produce low cost construction materials but also lead to sustainable development [2, 3, 9]. Development of non-expensive and environmentally friendly VA based concrete with acceptable strength and durability characteristics can be extremely helpful in the development and rehabilitation of volcanic disaster areas around.

However, the finely divided silica (50.76%) in VA can combine with calcium hydroxide in the presence of water to form stable compounds like calcium silicates, which have cementitious properties [10]. Such pozzolanic action of VA can contribute to the enhancement of strength and long-term durability of volcanic ash concrete.

Previous investigation showed that VA addition to concrete improves long-term corrosion resistance, lower corrosion rate and lower weight loss of embedded steel bars [14]. The role of VA is related with both the initiation and the progression of corrosion. The pozzolanic reaction of VA with calcium hydroxide also produces a denser concrete and thus inhibits the ingress of chloride ions. This takes place at a slower rate.

Various methods of improving the strength properties of concrete at reduce cost have been developed but the problem encountered when using volcanic ash is that as the percentage of partial replacement of cement increases from 0% to 30% ,the corresponding value of compressive strength decreases [15]. This is due to the low calcium oxide content of volcanic ash which stands at 11.67% as compared to 66% 67% of cement [16]. The need to boost the calcium oxide content with a view to improving the compressive strength of volcanic ash concrete becomes important.

This paper presents the results of an experimental investigation studying the effect of addition of Calcium Nitrate on selected properties of concrete containing Volcanic ash as partial replacement for ordinary Portland cement having a 28-day compressive strength of $25KN/m^2$ target strength in order to determine whether the strength of concrete made with volcanic ash/OPC could be improved through the boosting of the calcium oxide (CaO) which is a significant factor in strength acquisition of concrete products.

Material and Method

The coarse aggregate used for this research work was obtained from a local quarry behind F-layout minna Niger state, and fine aggregate was river sand, cement used was Dangote Portland cement (OPC) and the volcanic ash was obtained from the foot of Dutsen Dushowa at kerang in Mangu Local government area of plateau state,. The calcium Nitrate was obtained from a commercial seller in Kateren Gwari Minna, Niger state.

The control mixture was proportioned for a target concrete strength of 25 N/mm^2 and had a cementitious material content of 302 kg/m^3 fine aggregate content of 682 kg/m^3, a coarse aggregate content of 1149 kg/m^3 and a water cementitious materials ratio of 0.55 giving a free water content of 187 kg/m^3. The cement replacement by VA was thereby computed for by weight as required. The following test was carried out on fine and coarse aggregate and volcanic ash; specific gravity, Bulk density, and workability test on fresh concrete [17]. Setting time test was also conducted. 120 concrete cubes were cast containing the constituent material, Aggregates, volcanic ash at 10% of ordinary Portland cement, calcium nitrate at 0%, 2% ,4%, 6%, 8%, 10% by weight of volcanic ash , each resulting concrete cube measuring 150 × 150 × 150 mm was then cured under water for 7, 14, 21,and 28 days respectively . Water cement ratio of 0.5 was used for the concrete mix.

Chemical analysis of VA was carried out at National Metallurgical Development Centre, Jos. The X-ray Analyzer together with Atomic Absorption Spectrophotometer (AAS) was employed for the analysis of calcium oxide content in volcanic ash. Admixture is capable of imparting considerable physical and economic benefits with respect to concrete. These benefits include the use of concrete under circumstances where previously there existed considerable or even insuperable difficulties. According to ASTM C 492-92[18], admixtures are referred to as accelerators. Their function is primarily to concrete (i.e. hardening) although they may also coincidentally accelerate the setting of concrete.

Calcium nitrate also called norgessalpeter (Norwegian salt peter) and kalksal peter is a white color soluble salt with formula $Ca(NO_3)_2 \cdot 4H_2O$. It is deliquescent, readily absorbing moisture from the air. It has several applications such as, apyrophoric, a reagent and a fertilizer. Industrial quality calcium nitrate, when added to concrete acts as a set accelerator, counteraction of retardation by plasticizers while maintaining rheology, long term strength enhancer, antifreeze admixture or winter concreting admixture and inhibitor against chloride induced corrosion [19]. The main reason for the inclusion of calcium nitrate in this concrete is that it serves as a set accelerator i.e. (reducing setting time) giving high initial strength, reduce bleeding and improve workability. A Study conducted by Justness [20], Showed that calcium nitrate is a corrosion inhibitor and also a long term strength improver because of the fact that it is chloride free, and also it is the most economical and effective accelerator in modern day.

Results and Discussion

As shown in Table 1, the total content of Silicon Dioxide (SiO_2), Aluminium Oxide (Al_2O_3) and Iron (II) Oxide (Fe_2O3) is 71.62%, which is slightly above the minimum of 70% specified in ASTM C618 [21].

Table 1. Chemical Analysis of Kerang's Volcanic Ash Sample

Elements	% Composition by weight	Elements	% Composition by weight
SiO_2	50.76	P_2O_5	0.81
Al_2O_3	26.56	TiO_2	-
Fe_2O_3	3.34	MnO	-
CaO	11.67	SO_3	-
MgO	4.24	Cr_2O	-
K_2O	5.71	L.O.I	2.71
Na_2O	3.83	**Total SiO_2+Al_2O_3+Fe_2O_3**	**67.14**

Table 2 presents the specific gravity of the VA sample as 3.05, a value less than that of cement (3.15) as provided by Neville [22], it also as a bulk density of 1521.5kg/m^3. The fine aggregate sample has a specific gravity of 2.60, bulk density of 1287 kg/m^3, the coarse aggregate sample has 2.68Kg/m^3 and 1430Kg/m^3 specific gravity and bulk density respectively.

Table 2. Specific Gravity and Bulk Density

No	Materials	Specific Gravity	Bulk Density (Kg/m^3)
1	Fine Aggregate	2.60	1287
2	Coarse Aggregate	2.68	1430
3	Volcanic Ash	3.05	1521.5

Table 3, however shows the result of Chemical Analysis carried out on the volcanic ash. Volcanic ash blended with 10% Calcium Nitrate (Ca $(NO_3)_2$) sample. The CaO content in Volcanic ash blended with 10% Calcium Nitrate (Ca $(NO_3)_2$) increased by 65.35% rate of increase when compared with wholesome VA.

Table 3. Result of Chemical Analysis of CaO Content in Volcanic Ash

No	Sample	CaO (%)
1	Volcanic Ash	11.67
2	Volcanic Ash + 10 % $Ca(NO_3)_2$	33.68

Workability of the concrete decreases as the percentage of calcium nitrate ($Ca(NO_3)_2$) increases. The slump value ranges between 40-60mm. The setting time (initial and final) of the replacement are within the provision of BS EN 196-3 [23] limits of not less than 45 minutes initial and not more than 10 hours of finals setting time and also satisfy the requirements of both Portland fly ash and Portland cement (figure 1). The variation of setting times with 10% of VA and varying percentage of Calcium Nitrate is presented in Figure 1.

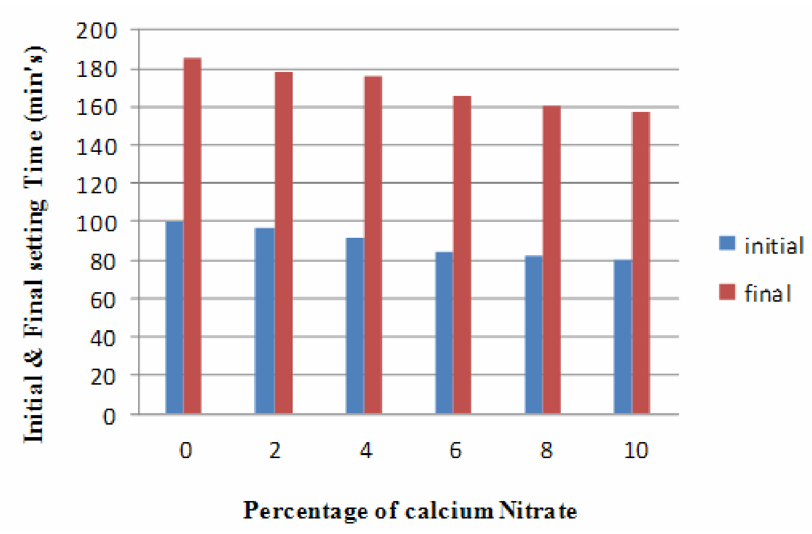

Figure 1. *Initial and Final setting time of varying percentage of Calcium Nitrate used with 10% partial replacement of cement with Volcanic Ash*

It was observed that an increase in percentage of Calcium Nitrate ($Ca(NO_3)_2$) reduces the initial and final setting time. This may be attributed to the increase in the concentration of calcium cations which boosted the low calcium oxide content of volcanic ash. "Ca2+ dominates setting, while NO_3 may have an effect as well, depending on cement type" [21].

Results of the compressive strength developed with hydration period of 7, 14, 21 and 28 days respectively for all percentage increment of Calcium Nitrate with their corresponding densities were presented in Tables 4-7. The percentage increment of Calcium Nitrate generally showed that there is an increment in the compressive strength of the cubes from 7 to 28 days respectively (Figure 2). The result is supported by Neville [24], that the addition of an admixture can boost the lime content of volcanic ash.

Table 4. Compressive Strength of Concrete Cube at 7 Days Hydration

Percentage of Calcium Nitrate	Mean Compressive (X_n) Strength (N/mm^2)	Mean Density (Kg/m^3)
0	15.86	2438
2	16.79	2483
4	17.64	2510
6	18.63	2448
8	19.47	2481
10	20.62	2408

Table 5. Compressive Strength of Concrete Cube at 14 Days Hydration

Percentage Of Calcium Nitrate	Mean Compressive (X_n) Strength (N/mm^2)	Mean Density (Kg/m^3)
0	19.56	2408
2	20.81	2437
4	22.60	2492
6	23.56	2255
8	25.26	2379
10	26.01	2398

Table 6. Compressive Strength of Concrete Cube at 21 Days Hydration

Percentage of Calcium Nitrate	Mean Compressive (X_n) Strength (N/mm^2)	Mean Density (Kg/m^3)
0	21.01	2386
2	22.55	2384
4	24.46	2416
6	25.72	2382
8	28.31	2397
10	29.34	2401

Table 7. Compressive Strength of Concrete Cube at 28 Days Hydration

Percentage Of Calcium Nitrate	Mean Compressive (X_n) Strength (N/mm^2)	Mean Density (Kg/m^3)
0	23.62	2480
2	24.36	2435
4	26.47	2429
6	28.52	2474
8	31.11	2493
10	33.87	2440

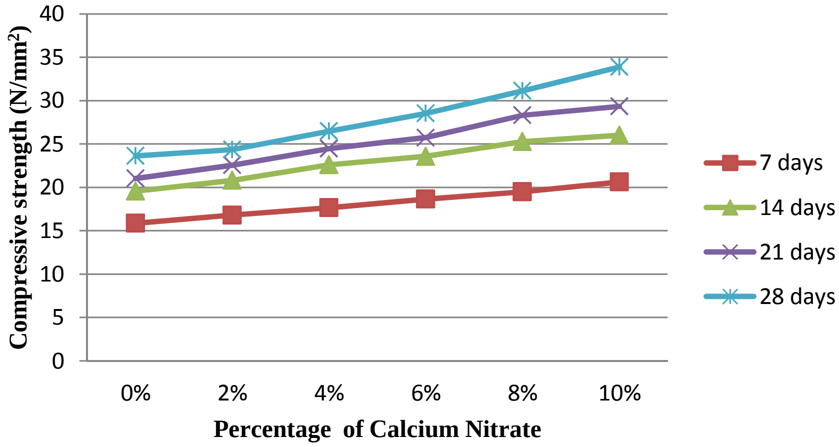

Figure 2. *Effect of Calcium Nitrate on compressive strength of concrete containing Volcanic Ash cured at 7, 14, 21 and 28days respectively*

Conclusions

This paper revealed that the addition of Calcium Nitrate as an admixture on concrete containing VA can improve the properties of the resulting concrete, providing an acceptable strength and durability characteristics. The following finales were drawn from the study:

1. Non-air entrained concrete containing volcanic ash as partial replacement for ordinary Portland cement with Calcium Nitrate as admixture exhibited a slump value that ranged between 63 mm and 75 mm, and this showed a satisfactory workability with no segregation or excessive bleeding.
2. The setting time of the concrete reduces as percentage of calcium nitrate increases, this is said to be responsible for the strength gain in concrete containing volcanic ash (i.e. as calcium nitrite percentage increase from 0% to 10%).
3. The specific gravity of volcanic ash is 3.05, and the result of chemical analysis of volcanic ash showed an increase in calcium oxide (CaO) content when calcium nitrites [$Ca(NO_3)_2$] was added at 10%, from 11.67% to 33.68% and this describe the strength boosting effect of calcium nitrites on volcanic ash which contains very low percentage of lime
4. Generally strength decreased with the increase of VA content and increased with the Concrete age. Concrete containing volcanic ash having a 28-day compressive strength with a target strength of $25KN/m^2$ can be achieved by using up to 10% VA and an

admixture ($Ca(NO_3)_2$ of up to 10%.

5. The statistical analysis carried out on the compressive strength value as the hydration period increase from 7 to 28 days. This increase in strength was also recorded as being proportional to the increase in calcium nitrates [$Ca(NO_3)_2$] content.

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References

1. Ogunbode E.B., Akanmu W.P., *Turning waste to wealth: Potential of Laterized Concrete Using Cassava Peels Ash (CPA) Blended Cement*, International Journal of Engineering Research & Technology (IJERT) 2012, 1(3), Available at: http://www.ijert.org/browse/may-2012-edition?start=80.
2. Hossain K.M.A., *Blended cement using volcanic ash and pumice*, Cem. Concr. Res., 2003, 33(10), p. 1601-1605.
3. Hossain K.M.A., *Properties of volcanic ash and pumice concrete*, IABSE Rep., 1999, 80, p. 145-150.
4. Al-Ani M., Hughes B., *Pulverized-fuel ash and its uses in concrete*, Mag. Concr. Res., 1989, 41(147), p. 55-63.
5. Swamy R.N., *Cement Replacement Materials*, Concrete Technology and Design, 3, Surrey University Press, Great Britain, 1986.
6. Berry E.E., Malhotra V.M., *Fly ash for use in concrete—a critical review,* J. of ACI 1980, 77(8), p. 59-73.
7. Bilodeau A., Malhotra V.M., *High volume fly ash system: concrete solution for sustainable development*, ACI Mater. J. 2000, 99(1), p. 41-48.
8. Hooton R.D., *Canadian use of ground granulated blast-furnace slag as a supplementary cementing material for enhanced performance of concrete*, Canadian J. Civ. Eng. 2000, 27, p. 754-760.
9. Hossain K.M.A., *Properties of volcanic pumice based cement and lightweight concrete,* Cement Concrete Research. 2004, 34(2), p. 283-291.
10. Hossain K.M.A., *Performance of volcanic ash based precast and in-situ blended cement*

concretes in marine environment, ASCE J. Mater. Civ. Eng. 2005, 17(6), p. 694-702.

11. Hossain K.M.A., Lachemi M., *Corrosion resistance and chloride diffusivity of volcanic ash blended cement mortar*, Cement and Concrete Research. 2004, 34(4), p. 695-702.
12. Ogunbode E.B., Olawuyi B.J., *Strength Characteristics of Laterized Concrete Using Lime-Volcanic ash cement*, Environmental Technology & Science Journal (ETSJ), 2008, 3(2), p. 81-87.
13. Hossain K.M.A., Lachemi M., *Strength, durability and micro-structural aspects of high performance Volcanic ash concrete*, Cement and Concrete Research, 2007, 37(1), p. 759-766.
14. Hossain K.M.A., *Chloride induced corrosion of reinforcement in volcanic ash and pumice based blended concrete*, Cement and Concrete Composite. 2005, 27(3), p. 381-390.
15. Hassan I.O., *Strength Properties of Concrete Obtained With Volcanic Ash Pozzolana In Partial Replacement of Cement*, An Unpublished M.Sc Thesis, University of Jos, p. 2-20, 2006.
16. Neville A.M., Brooks J.J., *Concrete Technology*, 2nd Edition. Longman Publishing Ltd, London, 1997.
17. British Standards Institution, *Methods of Testing the Workability of Fresh Concrete*. BS 5328 Part, London, 1991.
18. American standard for testing materials, *Specification for chemical admixtures for concrete*, ASTM 492-92, 1916.
19. Wikipedia (2006). http://en.wikipedia.org/wiki/concrete.
20. Justnes H., *Chloride free Actuator for Concrete Setting and Hardening*, proceedings of ACI/CAN MET Conference on Quality of Concrete Structures and Recent Advances in Concrete Materials and Testing. Recite, Brazil, 6 - 7 September 2005. p11.
21. American standard for testing materials, S*tandard specification for coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete*, Annual Book of ASTM Standards, ASTM C 618-00,Philadelphia, USA. 2000.
22. Neville A.M., *Properties of Concrete*, 4th Edition, copyright © 2000, Asia, Person Education Pte. Ltd, 2006.
23. British Standards Institution, *Methods of testing cement: Determination of setting times and soundness*, BS EN 196: Part 3, London, 2005.
24. Neville A.M., Brooks J.J., *Concrete Technology*, 2nd Edition. Longman Publishing Ltd. London, 1997.